

FORM PTO-1390 (Modified)
(REV 10-95)

U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE

ATTORNEY'S DOCKET NUMBER

TRANSMITTAL LETTER TO THE UNITED STATES
DESIGNATED/ELECTED OFFICE (DO/EO/US)
CONCERNING A FILING UNDER 35 U.S.C. 371

1447

U.S. APPLICATION NO. (IF KNOWN, SEE 37 CFR

09/744893

INTERNATIONAL APPLICATION NO.
PCT/DE 00/01878INTERNATIONAL FILING DATE
JUNE 8, 2000PRIORITY DATE CLAIMED
JUNE 22, 1999

TITLE OF INVENTION

METHOD FOR CALIBRATING THE OFFSET OF ANGLE SENSORS

APPLICANT(S) FOR DO/EO/US

Anton DUKART, Franz JOST

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☐ This is an express request to begin national examination procedures (35 U.S.C. 371(f)) at any time rather than delay examination until the expiration of the applicable time limit set in 35 U.S.C. 371(b) and PCT Articles 22 and 39(1).
4. ☐ A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.
5. ☒ A copy of the International Application as filed (35 U.S.C. 371 (c) (2))
 - a. ☐ is transmitted herewith (required only if not transmitted by the International Bureau).
 - b. ☒ has been transmitted by the International Bureau.
 - c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US).
6. ☒ A translation of the International Application into English (35 U.S.C. 371(c)(2)).
7. ☐ A copy of the International Search Report (PCT/ISA/210).
8. ☐ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371 (c)(3))
 - a. ☐ are transmitted herewith (required only if not transmitted by the International Bureau).
 - b. ☐ have been transmitted by the International Bureau.
 - c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
 - d. ☐ have not been made and will not be made.
9. ☐ A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
10. ☒ An oath or declaration of the inventor(s) (35 U.S.C. 371 (c)(4)).
11. ☐ A copy of the International Preliminary Examination Report (PCT/IPEA/409).
12. ☐ A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371 (c)(5)).

Items 13 to 18 below concern document(s) or information included:

13. ☒ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
14. ☒ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
15. ☐ A **FIRST** preliminary amendment.
A **SECOND** or **SUBSEQUENT** preliminary amendment.
16. ☐ A substitute specification.
17. ☐ A change of power of attorney and/or address letter.
18. ☒ Certificate of Mailing by Express Mail
19. ☐ Other items or information:

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Page 2 of 2

4/PRTS

09/744893

JC07 Rec'd PCT/PTO 31 JAN 2001

METHOD FOR CALIBRATING THE OFFSET OF ANGLE SENSORS

The present invention relates to a method for calibrating the offset of angle sensors, which determine an angle to be determined on the basis of a sine signal that can be assigned to the angle and a cosine signal that can be assigned to the angle.

For measuring mechanical angles, measuring methods that are based on the evaluation of sine signals and cosine signals of a sensor are often employed. As examples that can be named in this respect are resolvers in the form of inductive transducers, anisotropic magnetoresistive sensors (AMR sensors), sensors which exploit the giant magnetoresistive effect (GMR sensors), Hall sensors in the form of magnetic angle encoders, and optical or micromechanical transducers.

AMR sensors are used for measuring steering wheel angles, for instance. In such sensors, the angle to be determined is determined via electronic processing of the sine signals and cosine signals of the sensors that can be assigned to the angle to be determined.

The angular precision of such sine-cosine sensors is limited by offset effects. Offset effects can occur especially when the sensors are used at high temperatures. For example, an angle measurement in the motor vehicle engine compartment, where high temperatures typically prevail, leads in the case of conventional angle sensors to offset effects that are not negligible. As a result, the ranges of production variation and operating tolerances for the mechanical,

magnetic, optical or micromechanical components of such sensors must be set as low as possible, which increases their production costs.

5 The object of the present invention is to disclose a method with which in a simple way the angular precision in angle sensors, especially in angle measurements at high temperatures, can be improved without having to make overly stringent demands in terms of operating tolerance ranges.

10 This object is attained by a method having the characteristics of claim 1. By means of the method of the invention, the offset of an angle sensor can be calculated and compensated for in a simple way during operation. Compared with conventional versions, this
15 makes it possible to enhance the angular precision, and in particular satisfactory angle measurements can be made at high temperatures, such as in the engine compartment of motor vehicles. The invention makes it possible to increase the ranges of production variation or operating tolerances for the mechanical, magnetic,
20 optical or micromechanical components of the sensors used.

Advantageous features of the method of the invention are the subject of the dependent claims.

25 In an especially preferred feature of the method of the invention, the determination of the offset O_{sin} of the sine signal is done in accordance with an equation

$$O_{sin} = 1/2 * \{ U_{cos}(1) - U_{cos}(3) + [(U_{sin}(2) - U_{sin}(1)) * (U_{sin}(2) + U_{sin}(1)) / (U_{cos}(2) - U_{cos}(1)) - [(U_{sin}(3) - U_{sin}(2)) * (U_{sin}(3) + U_{sin}(2)) / (U_{cos}(3) - U_{cos}(2))]] / [(U_{sin}(2) - U_{sin}(1)) / (U_{cos}(2) - U_{cos}(1)) - (U_{sin}(3) - U_{sin}(2)) / (U_{cos}(3) - U_{cos}(2))] \},$$

and the determination of the offset O_{cos} of the cosine signal is done in accordance with an equation

$$O_{cos} = 1/2 * \{ U_{sin}(1) - U_{sin}(3) + [(U_{cos}(2) - U_{cos}(1)) * (U_{cos}(2) + U_{cos}(1)) / (U_{sin}(2) - U_{sin}(1)) - [(U_{cos}(3) - U_{cos}(2)) * (U_{cos}(3) + U_{cos}(2)) / (U_{sin}(3) - U_{sin}(2))]] / [(U_{cos}(2) - U_{cos}(1)) / (U_{sin}(2) - U_{sin}(1)) - (U_{cos}(3) - U_{cos}(2)) / (U_{sin}(3) - U_{sin}(2))] \},$$

in which $U_{sin}(i)$, $U_{cos}(i)$ represent the determined sensor signals for the positions $i = 1, 2, 3$.

The equations given contain merely elementary operations with regard to three pairs of measurement values, each for different angles. Other types of calculation and in particular trigonometric types of calculation are also possible.

The method according to the invention will now be explained further in conjunction with the accompanying drawing. Shown in this drawing are:

Fig. 1, a graph to schematically illustrate sine signals and cosine signals that can be assigned to an angle;

Fig. 2, a graph to illustrate the offset of an ideal sensor;

Fig. 3, a graph to illustrate the offset of a real sensor; and

Fig. 4, a graph to illustrate the method of the invention, on the basis of three different angular positions of an angle to be determined.

Numerous angle sensors, for certain angular positions that can for instance be represented in the form of angles between the sensor and a rotatable permanent magnet, generate two different signal values, which correspond to the sine and the cosine, respectively, of the angle to be determined. Such sine and cosine signals are schematically shown in Fig. 1. A cosine signal is represented here by the symbol U_{\cos} , and a sine signal is represented by the symbol U_{\sin} . It can be seen that at an angle φ of 0° , a signal U_{\sin} of 0 and a signal U_{\cos} of 1 are present, which corresponds to an ideal sensor without an offset. The signals of such an ideal sensor for angle measurement are $U_{\sin}(\varphi) = A * \sin(\varphi)$, and $U_{\cos}(\varphi) = A * \cos(\varphi)$, in which U_{\sin} and U_{\cos} are the sensor signals, A is the amplitude of the signal, and φ represents the mechanical angle. On the basis of two such measurement values, the mechanical angle can be calculated, for instance by means of the relationship $\arctan(U_{\sin}(\varphi)/U_{\cos}(\varphi))$.

The ideal state in which no offset in the signals of the angle sensor occurs is shown once again in Fig. 2 in a further graph. Here the signal U_{\sin} is plotted on the abscissa, and the signal U_{\cos} is plotted on the ordinate. Since the offset values of both signals are equal to 0, that is, $O_{\sin}=0$ and $O_{\cos}=0$, all the value pairs U_{\cos} , U_{\sin} detected are located on an arc K .

In actual or available angle sensors, however, an offset occurs with regard to both signals, resulting in the following equations:

$$U\sin(\varphi) = O\sin + A * \sin(\varphi), \text{ and}$$

$$U\cos(\varphi) = O\cos + A * \cos(\varphi).$$

The occurrence of such an offset makes angle measurements actually performed incorrect. This real situation is shown in Fig. 3. It can be seen that the offset values $O\sin$ and $O\cos$ are different from 0. The value pairs obtained when such an offset is present are located on an arc K' , which however instead of the ideal zero point has the point $(O\sin, O\cos)$ as its center point.

The method according to the invention now makes a simple determination of the offset values $O\sin$ and $O\cos$ possible, so that on the basis of these determined offset values, a cleaned-up angle calculation can be done.

The problem on which the invention is based resides in the determination of the center point of a circle of which only various points along the arc are known.

Solving this problem will now be explained in further detail in conjunction with Fig. 4. In the example shown there, the center point 0 of the circle is determined on the basis of three points 1, 2, 3 that are located on the arc K' . The coordinates of the various points are as follows:

- 1: $U_{\sin}(1), U_{\cos}(1);$
- 2: $U_{\sin}(2), U_{\cos}(2);$ and
- 3: $U_{\sin}(3), U_{\cos}(3).$

In other words, in the present example the determination of the center point 0 of the circle K' is shown on the basis of the three points 1, 2, 3 of the circle. The coordinates of the center point 0 of the circle correspond to the coordinates of the offset, namely $O_{\sin}, O_{\cos}.$

Since all three points are located on the circle K' , the following conditions apply:

$$[(O_{\cos}-U_{\cos}(1)]*[(O_{\cos}-U_{\cos}(1)]+[(O_{\sin}-U_{\sin}(1)]*[(O_{\sin}-U_{\sin}(1)]=[(O_{\cos}-U_{\cos}(2)]*[(O_{\cos}-U_{\cos}(2)]+[(O_{\sin}-U_{\sin}(2)]*[(O_{\sin}-U_{\sin}(2)],$$

and

$$[(O_{\cos}-U_{\cos}(2)]*[(O_{\cos}-U_{\cos}(2)]+[(O_{\sin}-U_{\sin}(2)]*[(O_{\sin}-U_{\sin}(2)]=[(O_{\cos}-U_{\cos}(3)]*[(O_{\cos}-U_{\cos}(3)]+[(O_{\sin}-U_{\sin}(3)]*[(O_{\sin}-U_{\sin}(3)].$$

Solving these equations yields the following values for the coordinates of the center point of the circle K' , or in other words the offset values $O_{\sin}, O_{\cos}:$

$$\begin{aligned} & \text{Usin}(1)) * (\text{Usin}(2) + \text{Usin} \\ & (1)) / (\text{Ucos}(2) - \text{Ucos}(1)) - [(\text{Usin}(3) - \\ & \text{Usin}(2)) * (\text{Usin}(3) + \text{Usin}(2) / (\text{Ucos}(3) - \text{Ucos}(2))) / [(\text{Usin}(2) - \\ & \text{Usin}(1)) / (\text{Ucos}(2) - \text{Ucos}(1)) - (\text{Usin}(3) - \text{Usin}(2)) / (\text{Ucos}(3) - \\ & \text{Ucos}(2))], \end{aligned}$$

$$\begin{aligned} \text{Ocos} = & 1/2 * \{ \text{Usin}(1) - \text{Usin}(3) + [(\text{Ucos}(2) - \text{Ucos}(1)) * (\text{Ucos}(2) + \\ & \text{Ucos}(1)) / (\text{Usin}(2) - \text{Usin}(1)) - [(\text{Ucos}(3) - \text{Ucos}(2)) * (\text{Ucos}(3) + \\ & \text{Ucos}(2) / (\text{Usin}(3) - \text{Usin}(2))]] / [(\text{Ucos}(2) - \text{Ucos}(1)) / (\text{Usin}(2) - \\ & \text{Usin}(1)) - (\text{Ucos}(3) - \text{Ucos}(2)) / (\text{Usin}(3) - \text{Usin}(2))] \}. \end{aligned}$$

The formulas for representing the offset values Osin, Ocos contain merely elementary operations of the three pairs of measurement values for the various angles. The offset values Osin, Ocos can therefore be determined in a simple way on the basis of the calculation method indicated.

It will be noted that the temperature should not vary during the detection of the three measurement value pairs 1, 2, 3, since the radius of the circle K' is dependent on the temperature, and hence temperature changes can lead to imprecisions.

Mathematical calculation methods known per se for calculating angles on the basis of sine signals and cosine signals can be expanded according to the invention with the automatic offset calibration shown.

The method illustrated permits an automatic offset calibration upon dynamic rotary motions. No change in the actual sensors is made, either in terms of layout, packaging or manufacture. The change takes place only in an evaluation circuit, and thus conventional sensors can continue to be used, given suitable modification of the evaluation circuit. If the evaluation circuit is

assigned to a microprocessor, only the software has to
be changed, by incorporating the indicated calculation
method for calculating the offset and compensating for
it. It is understood that hardware expansions of the
evaluation electronics are also possible. By means of
the method of the invention, new possible uses and new
possibilities for diagnosis in safety-relevant systems
become available. Examples that can be named in this
connection are ESP (electronic stability program) and
EPS (electronic power steering) with sensors for
measuring steering wheel angles, throttle adjustments,
and torque.

The method illustrated can advantageously be used
in particular in contactless steering wheel angle
measurement and torque measurement, regardless of any
measurement or sensor principle employed.

Claims

1. A method for calibrating the offset of angle sensors, which determine an angle to be determined on the basis of a sine signal that can be assigned to the angle and a cosine signal that can be assigned to the angle, having the following steps:

- determining the sine signal and the cosine signal for at least three different angles (1, 2, 3) to obtain at least three value pairs (Usin(1), Ucos(1); Usin(2), Ucos(2); Usin(3), Ucos(3)), each containing one sine signal and one cosine signal.

- displaying the at least three value pairs in an at least two-dimensional coordinate system that represents a sine signal-cosine signal plane; and

- determining a point, representing the offset to be calibrated, in the coordinate system with regard to which point the at least three value pairs are located on an arc.

2. The method of claim 1, characterized in that the offset Osin of the sine signal is determined in accordance with an equation

$$\begin{aligned} O_{\sin} = & 1/2 * \{ U_{\cos}(1) - U_{\cos}(3) + [(U_{\sin}(2) - \\ & U_{\sin}(1)) * (U_{\sin}(2) + U_{\sin}(1)) / (U_{\cos}(2) - U_{\cos}(1)) - [(U_{\sin}(3) - \\ & U_{\sin}(2)) * (U_{\sin}(3) + U_{\sin}(2)) / (U_{\cos}(3) - U_{\cos}(2))] / [(U_{\sin}(2) - \\ & U_{\sin}(1)) / (U_{\cos}(2) - U_{\cos}(1)) - (U_{\sin}(3) - U_{\sin}(2)) / (U_{\cos}(3) - \\ & U_{\cos}(2))] \} \end{aligned}$$

and the offset Ocos of the cosine signal is determined

in accordance with an equation

$$Ocos = 1/2 * \{ Usin(1) - Usin(3) + [(Ucos(2) - Ucos(1)) * (Ucos(2) + Ucos(1)) / (Usin(2) - Usin(1)) - [(Ucos(3) - Ucos(2)) * (Ucos(3) + Ucos(2)) / (Usin(3) - Usin(2))]] / [(Ucos(2) - Ucos(1)) / (Usin(2) - Usin(1)) - (Ucos(3) - Ucos(2)) / (Usin(3) - Usin(2))] \},$$

wherein $Usin(i)$, $Ucos(i)$ represent the determined sensor signals for the positions $i = 1, 2, 3$.

Abstract

A method for calibrating the offset of angle sensors, which determine an angle to be determined on the basis of a sine signal that can be assigned to the angle and a cosine signal that can be assigned to the angle, having the following steps:

- determining the sine signal and the cosine signal for at least three different angles to obtain at least three value pairs, each containing one sine signal and one cosine signal;

- displaying the at least three value pairs in an at least two-dimensional coordinate system that represents a sine signal-cosine signal plane; and

- determining a point, representing the offset to be calibrated, in the coordinate system with regard to which point the at least three value pairs are located on an arc.

1/4

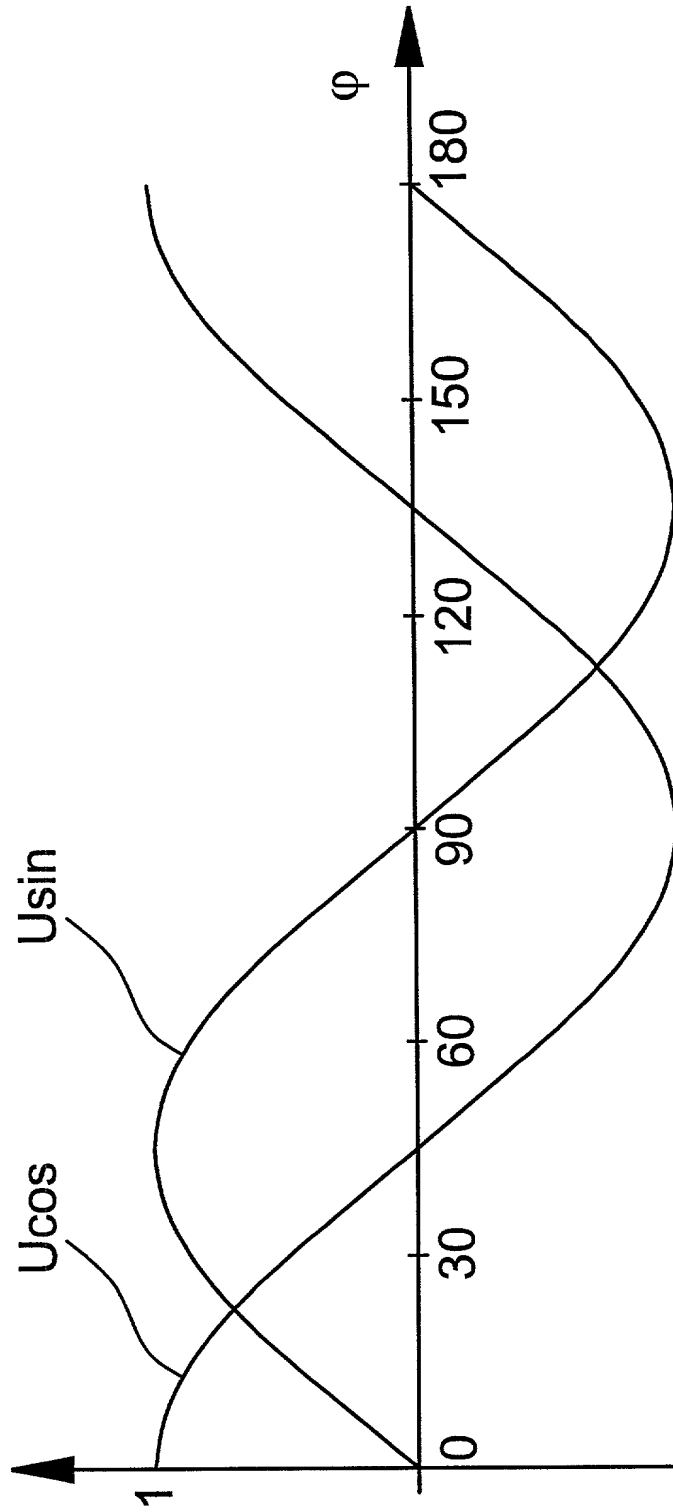
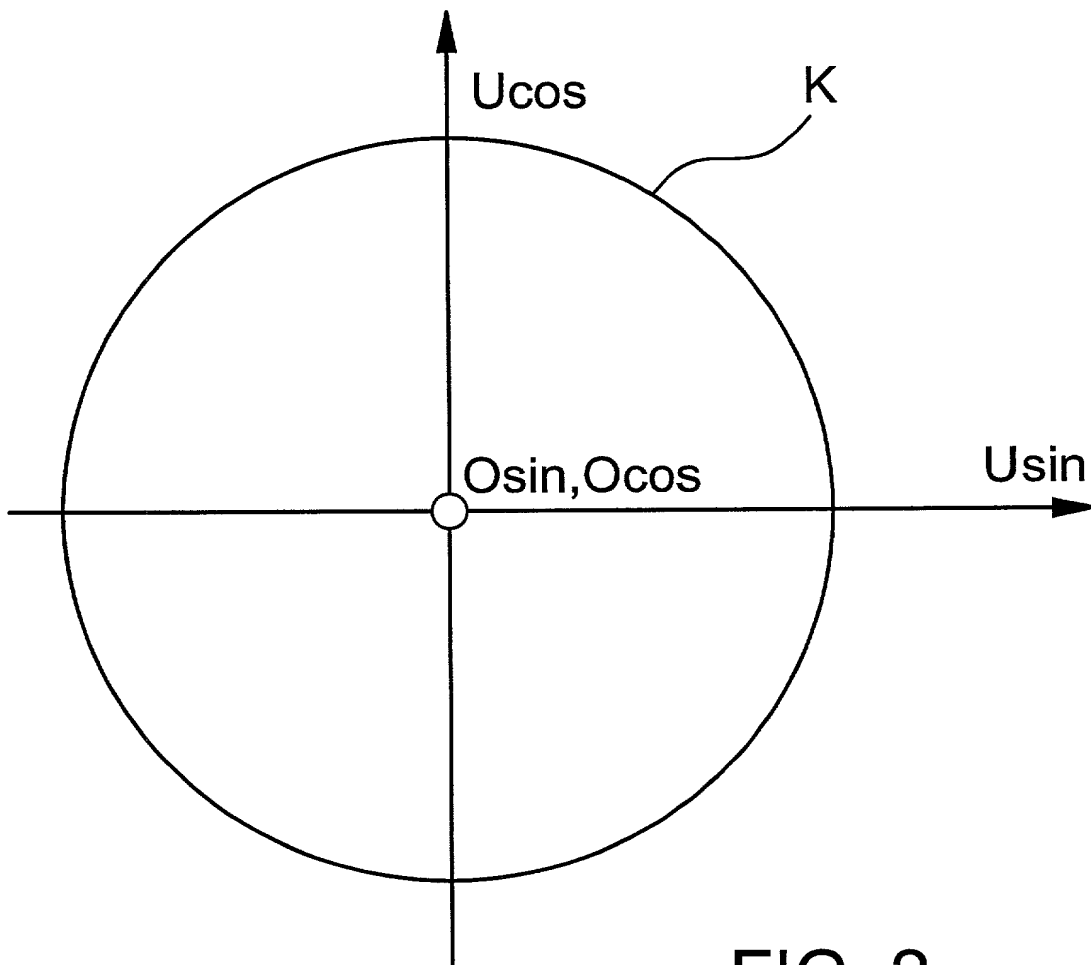


FIG. 1

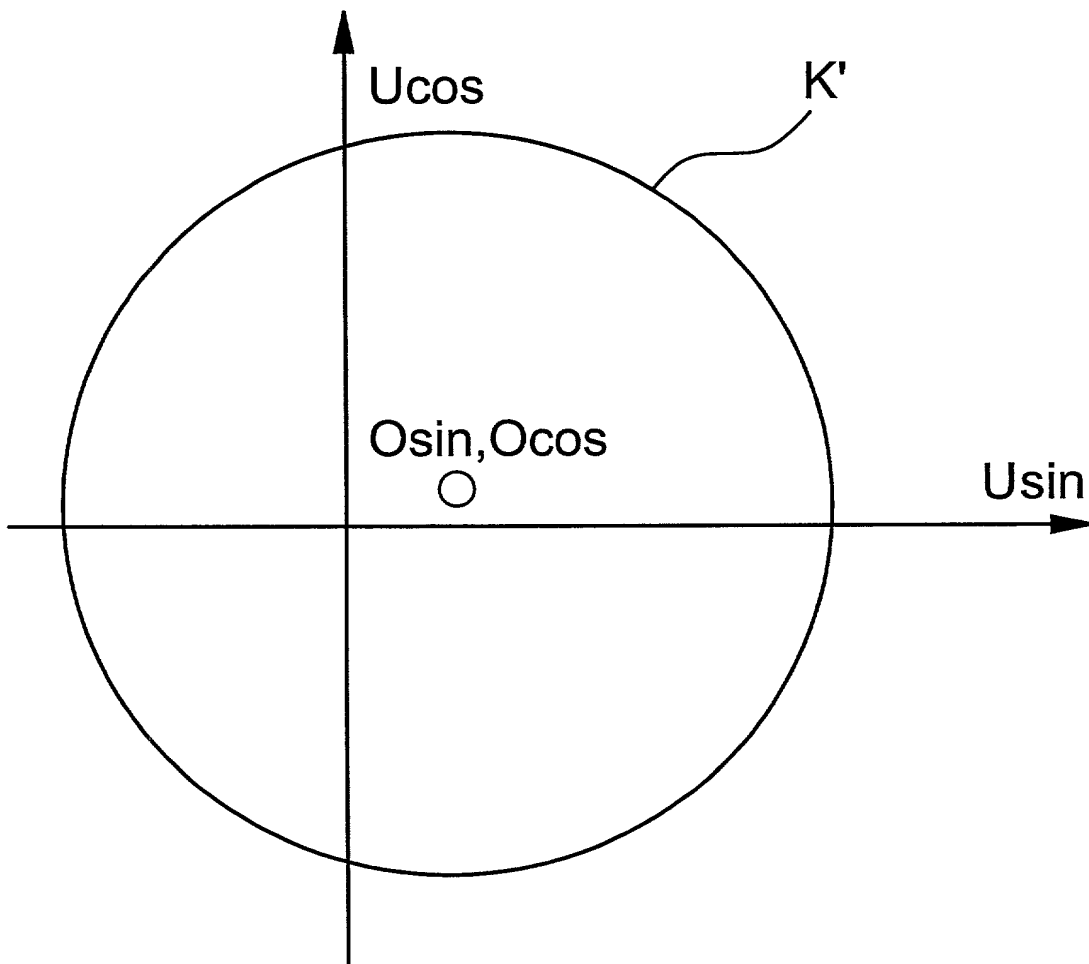
2/4



$$\begin{aligned} O \sin &= 0 \\ O \cos &= 0 \end{aligned}$$

FIG. 2

3/4



$O\sin \neq 0$
 $O\cos \neq 0$

FIG. 3

4/4

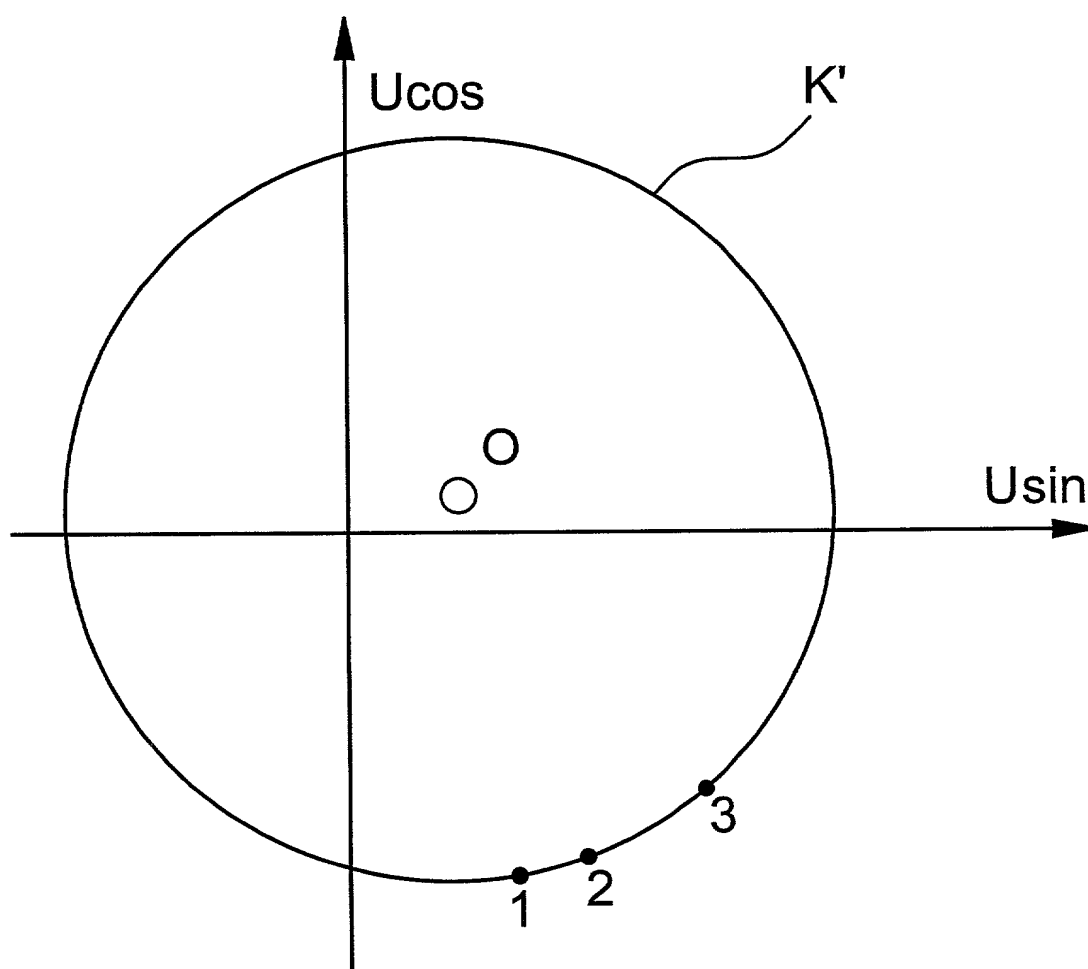


FIG. 4

Wertepaare:

$U_{\sin}(1), U_{\cos}(1)$

$U_{\sin}(2), U_{\cos}(2)$

$U_{\sin}(3), U_{\cos}(3)$

DECLARATION AND POWER OF ATTORNEY FOR NATIONAL STAGE OF PCT PATENT APPLICATION

As a below-named inventor, I hereby declare that:

Anton DUKART
Franz JOST

My residence, post office address and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor (if only name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled **METHOD FOR CALIBRATING THE OFFSET OF ANGLE SENSORS** the specification of which was filed as PCT International Application number PCT/DE 00/01878 on June 8, 2000.

I hereby state that I believe the named inventor or inventors in this Declaration to be the original and first inventor or inventors of the subject matter which is claimed and for which a patent is sought.

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose all information which is material to the patentability of this application in accordance with Title 37, Code of Federal Regulations, Section 1.56.

I hereby claim foreign priority benefits under Title 35, United States Code, Section 119(a)-(d) or Section 365 (b) of any foreign application(s) for patent or inventor's certificate, or Section 365(a) of any PCT International application which designated at least one country other than the United States, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate or PCT International application having a filing date before that of the application on which priority is claimed.

Prior foreign application(s):

Priority claimed:

| | | | | |
|---------------------|----------------|----------------------|----------|----|
| <u>199 28 482.2</u> | <u>GERMANY</u> | <u>JUNE 22, 1999</u> | <u>X</u> | |
| (Number) | (Country) | (Date filed) | Yes | No |
| (Number) | (Country) | (Date filed) | Yes | No |

As a named inventor, I hereby appoint the following attorney to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith:

Michael J. Striker, Reg. No. 27233

Direct all telephone calls to Striker, Striker & Stenby at telephone no.: (631) 549 4700 and address and all correspondence to:

STRIKER, STRIKER & STENBY
103 East Neck Road
Huntington, New York 11743
U.S.A.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that wilful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such wilful false statement

may jeopardize the validity of the application or any patent issued thereon.

| | | |
|--|--------------------------|--|
| Signature: <i>Anton Dukart</i> | Date: <i>11.01.01</i> | Residence and Full Postal Address: Eichenweg 1 70839 Gerlingen Germany <i>DEU</i> |
| Full Name of First or Sole Inventor: Anton DUKART | Citizenship: GERMAN | |
| Signature: <i>Franz Jost</i> | Date: <i>15.01.01</i> | Residence and Full Postal Address: Schoenbuchstrasse 30B 70565 Stuttgart Germany <i>DEU</i> |
| Full Name of Second Inventor: Franz JOST | Citizenship: GERMAN | |
| Signature: | Date: | Residence and Full Postal Address: |
| Full Name of Third Inventor: | Citizenship: | |
| Signature: | Date: | Residence and Full Postal Address: |
| Full Name of Fourth Inventor: | Citizenship: | |
| Signature: | Date: | Residence and Full Postal Address: |
| Full Name of Fifth Inventor: | Citizenship: | |
| Signature: | Date: | Residence and Full Postal Address: |
| Full Name of Sixth Inventor: | Citizenship: | |
| Signature: | Date: | Residence and Full Postal Address: |
| Full Name of Seventh Inventor: | Citizenship: | |
| Signature: | Date: | Residence and Full Postal Address: |
| Full Name of Eighth Inventor: | Citizenship: | |
| Signature: | Date: | Residence and Full Postal Address: |
| Full Name of Ninth Inventor: | Citizenship: | |